Effects of Shading Upland Vegetation on Egg Survival for Summer-spawning Surf Smelt on Upper Intertidal Beaches in Puget Sound

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Introduction

The surf smelt, *Hypomesus pretiosus*, is a common, nearshore-dwelling, marine forage fish found throughout the Puget Sound basin. It is an important trophic link in local nearshore food webs, and also supports localized commercial and recreational harvest fisheries for human consumption, as well.

The surf smelt is virtually unique among local marine fishes in its obligate usage of upper intertidal sand-gravel beaches for spawn deposition and incubation, sharing that spawning habitat context with local stocks of the Pacific sand lance, *Ammodytes hexapterus* (Penttila 1995). Surf smelt are known to spawn throughout Washington State, with some areas receiving spawn in the summer months, others in the fall-winter months, and still others throughout the year (Figure 1).

The known spawning beaches of the surf smelt are among those marine habitats listed in the Washington Administrative Code (WAC) Hydraulic Code Rules as being of "special concern." The Washington Department of Fish and Wildlife (Fish and Wildlife) endeavors to protect all known surf smelt spawning beaches from "net loss" from the cumulative impacts of human shoreline development. At present, surf smelt spawning habitat preservation efforts are primarily aimed at protecting upper intertidal surf smelt spawning substrate zones from physical burial and the disruption of beach sediment supply and transport by armoring/filling activities.

An additional element of potential surf smelt spawning habitat quality that has received almost no investigative attention as been the degree of shading by overhanging trees and other terrestrial vegetation afforded the surf smelt spawning substrate zone, particularly for those populations spawning during the summer months. The possible temperature-moderation effects of shading vegetation have been noted in earlier studies (Schaefer 1936; Penttila 1973), but these observations were not coupled with data on the condition of incubating spawn.

This study summarizes data comparing *in situ* surf smelt spawn mortalities from coupled pairs of adjacent shaded and sun-exposed sites on northern Puget Sound beaches used during the summer months, collected during the course of Washington Department of Fisheries (WDF) and Fish and Wildlife surf smelt spawning habitat investigations undertaken during the 1099-1998 period.

Methodology

Surf smelt spawning habitat investigations have been undertaken by WDF/ Fish and Wildlife from 1972 to the present. Such investigations have routinely included the collection and analyses of carefully documented spawn samples from a wide range of spawning sites. For the purposes of this study, survey records were searched for fortuitous instances where surf smelt spawn samples had been collected and preserved from clearly noted, adjacent "shaded" and "unshaded" sites on the same survey day during the months of July, August and September. Weather conditions or site-specific ambient temperature data were not recorded, but were presumed to be seasonably warm and dry during at least part of the sampled spawn's roughly two-week summer incubation period. The existence and relative rate of groundwater seepage through the upper intertidal beach, another possibly important factor in the survival of incubating surf smelt spawn, was not recorded.

"Shaded" sites, described as such in written field notes recorded during the surveys, were estimated to have at least 50% of the overhead sky obscured by overhanging vegetation, generally the canopies of deciduous trees. "Shaded" sites might have been exposed to full sunlight for relatively brief periods in the morning and evening, depending on the compass orientation of the shoreline. “Shaded” sites might also be exposed to desiccating wind regimes similar to those of their adjacent “unshaded” comparison sites.

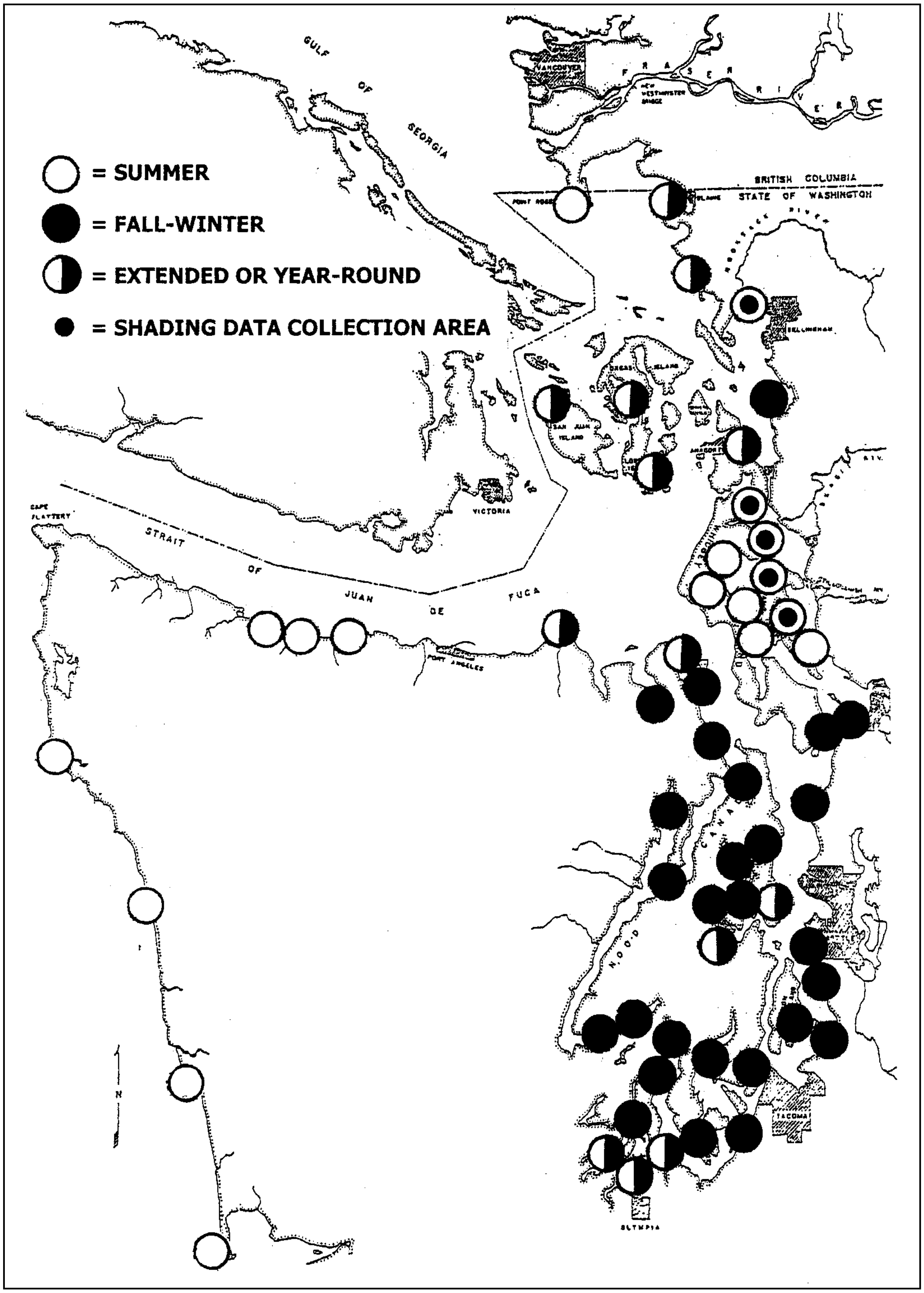

Figure 1. Surf smelt *(Hypomesus)* spawning areas and seasons in Washington State, with spawn-shading effect data collection areas indicated.

"Unshaded" sites, again referred to as such in written survey field notes, had no such overhanging tree canopies overhead or in the immediate vicinity. Depending on the local topography, "unshaded" sites might have been shaded during part of the day by shoreline bluffs.

The physical distances between couplets of "shaded" and "unshaded" spawning sites varied from about 50 feet (15 m) in those instances when sample pairs were collected from disparate microhabitats within a single survey station, to 6000 feet (1830 m) in those instances where selected pairs were from adjacent survey stations along the beach. Selected couplets were from shorelines with approximately the same compass orientation, and were presumed to have experienced the same ambient climate.

During the course of WDF/Fish and Wildlife surf smelt spawning habitat surveys, surf smelt spawn samples were collected from the surface-inch (2.5 cm) of the beach, and were routinely analyzed for spawn density (eggs /gram of substrate), spawn age distribution, and percentage of dead or clearly desiccated eggs present. Samples used in this study were generally collected from relatively dense spawn deposits visible on the surface of the beach. While initially ignoring the percent-dead figures, an attempt was made to select and compare "shaded" and "unshaded" sample couplets that had similar egg densities and age distributions.

For a statistical analysis of the data set, the *in situ* percent mortalities for "shaded" and"unshaded" spawn samples were pooled separately, with a null-hypothesis stating that there would be no significant difference between the "shaded" and "unshaded" spawn's mean percent mortality. Because the original data were in percentages, it underwent an arc-sine transformation, and a paired-two-sample-for-means t-test, to test the null hypothesis (Zar 1974).

Results

Of approximately 1000 surf smelt spawning beach survey stations that were undertaken by WDF/Fish and Wildlife in summer spawning areas during the 1990-1999 period, a total of 37 couplets of adjacent, unambiguously "shaded" and "unshaded" spawn samples were found satisfying the selection criteria of this study. The sites selected were from a number of spawning areas: northern Bellingham Bay, Dugualla Bay, northern Camano Island, and the west shore of Port Susan (Figure 1).

The mean percent dead eggs in "shaded" sites was 35.6%, while that for "unshaded" sites was 59.7%. The *in situ* "condition" of surf smelt spawn incubating during the summer months was found to be quite variable, presumably due to the effects of variable weather conditions and variable incubation times within the spawning substrate, neither of which were incorporated into this analysis. A scatter diagram of the mortality percentages of the selected couplets clearly suggests a tendency toward higher mortalities at sun-exposed locations, and conversely no suggestion that summer sun exposure is advantageous for surf smelt spawn survival (Figure 2).

The results of the t-test on the paired mortality data found a very significant difference between "shaded" and "unshaded" conditions (t (0.05(2)36)= 9.659), and rejected the null hypothesis that there was no difference in the means of the two treatments (Table 1).

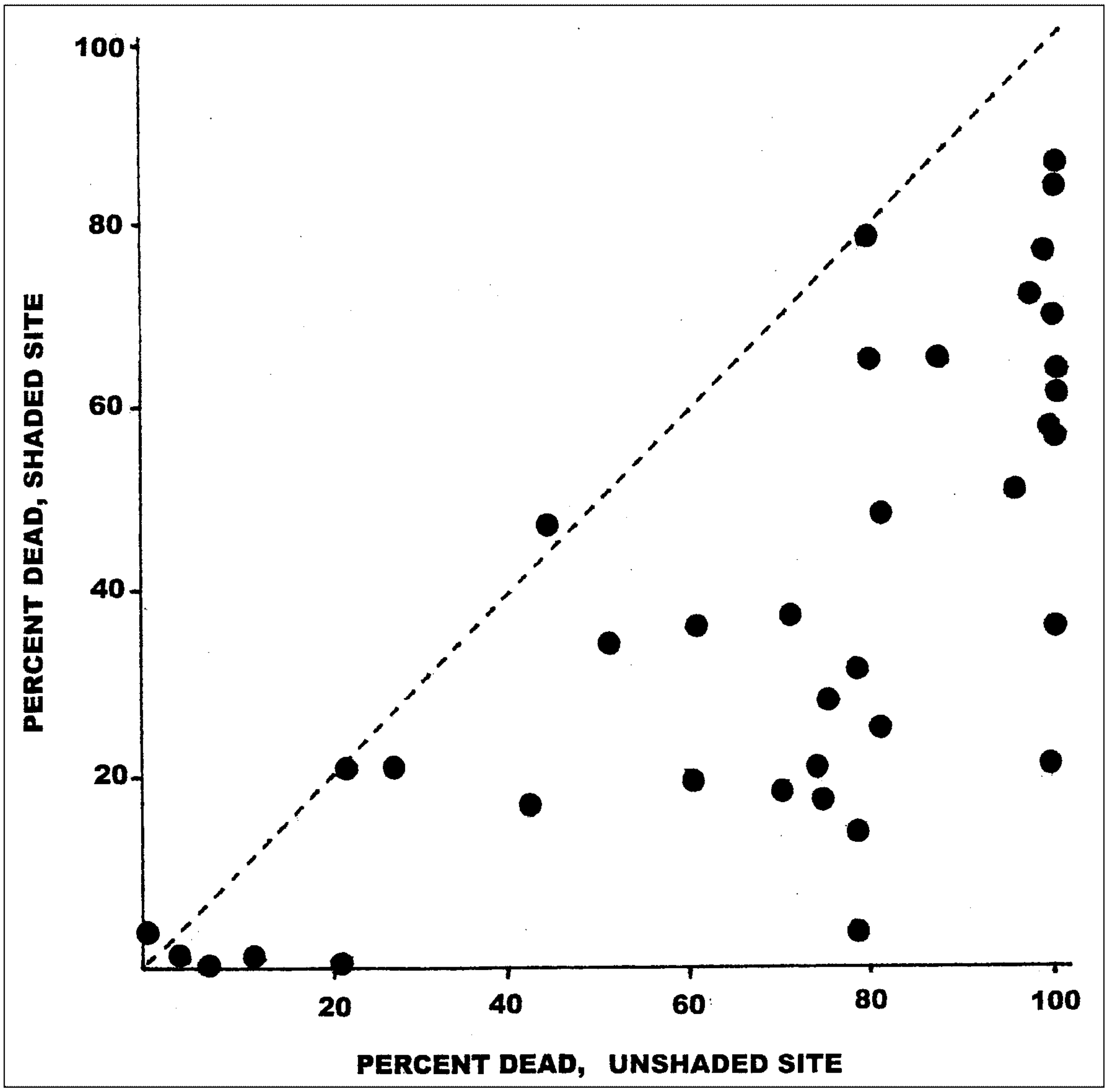

Figure 2. Scatter diagram of relationship of *in situ* surf smelt spawn mortalities at 37 “shaded” and “unshaded” spawning site couplets.

Table 1. Summary of statistical analysis comparing mean surf smelt spawn mortalities at "shaded" and "unshaded" spawning site couplets.

	Original Data			Arcsine-Transformed Data	
Couplet No.	**Variable 1** (Unshaded)	**Variable 2** (Shaded)	Couplet No.	**Variable 1** (Unshaded)	**Variable 2** (Shaded)
1	78.4 %	32.4 % Dead	1	62.3 %	34.7 % Dead
2	27.3	20.4	2	31.5	26.9
3	100	86	3	90	68
4	100	62.7	4	90	52.4
5	98.5	76.5	5	83	61
6	20.3	0	6	26.8	0
7	21.3	20.7	7	27.5	27.1
8	74.3	17	8	59.5	24.4
9	78.5	13.3	9	62.4	21.4
10	0.7	3.2	10	4.8	10.3
11	42.2	16.9	11	40.5	24.3
12	99.7	56.5	12	86.9	48.7
13	81.9	47.9	13	64.8	43.8
14	99	21.3	14	84.3	27.5
15	51.8	33.9	15	46	35.6
16	100	69.5	16	90	56.5
17	79.5	63.9	17	63.1	53.1
18	6.8	0	18	15.1	0
19	3.1	0.7	19	10.1	4.8
20	81.7	25.2	20	64.7	30.1
21	100	63.8	21	90	53
22	100	84.1	22	90	66.5
23	11.9	1	23	20.2	1.8
24	60.4	19.3	24	51	26.1
25	72	37.5	25	58.1	37.8
26	97.2	71.4	26	80.4	57.7
27	80.4	78.1	27	63.7	62.1
28	99.3	57.5	28	85.2	49.3
29	44	47.4	29	41.6	43.5
30	100	35.7	30	90	36.7
31	75.2	28.6	31	60.1	32.3
32	78.4	3.2	32	62.3	10.3
33	66.9	18.4	33	54.9	25.4
34	87.3	65	34	69.1	53.7
35	61.5	36.1	35	51.6	36.9
36	95.4	50.9	36	77.6	45.5
37	73.8	20.3	37	59.2	26.8

t-Test: Paired Two-Sample for Means

	Variable 1	*Variable 2*
Mean	59.6837838	35.5675675
Variance	610.351952	360.519474
Observations	37	37
Pearson Correlation	0.78899399	
Pooled Variance	485.435713	
Hypothesized Mean Difference	0	
df	36	
t	9.65890296	
P(T<=t) one-tail	7.786E-12	
t Critical one-tail	1.68829771	
P(T<=t) two-tail	1.557E-11	
t Critical two-tail	2.028094	

$\alpha = .05$

Discussion

The results of this *a posteriori* study strongly suggest that shading terrestrial vegetation, i.e. the canopies of full-sized deciduous trees, of the “marine riparian corridor” has a positive effect on the survival of surf smelt spawn incubating in sand-gravel beaches in the upper intertidal zone during the summer months in the Puget Sound basin. Such overhanging vegetation appears to serve the same function on marine beaches as it does on freshwater streams, moderating quasi-terrestrial ambient temperatures in microhabitats routinely occupied by sensitive and critical life history stages of demersal-spawning salmonoid fishes otherwise adapted to the region’s cold climatic conditions. It is presumed that increased surf smelt spawn survival to hatching is of net benefit to the species and the local marine nearshore food webs to which it contributes.

The results of this study most clearly apply to those relatively sheltered beaches in the Puget Sound basin used by spawning surf smelt during the summer months. Summer-spawning beaches, including those used by spawning surf smelt year-round, comprise roughly 50% of the approximately 200 statute miles (322 km) of documented spawning beaches in the state (Figure 1). Some surf smelt summer-spawning stocks utilize spawning areas with little or no shade from a marine riparian vegetation corridor, i.e. Washington’s outer coast, Strait of Juan de Fuca, Point Roberts, and northern Bellingham Bay. It may be significant that these spawning areas are also exposed to higher wave action regimes, which may result in spawn dispersal deeper into a thicker deposit of spawning substrate, allowing spawn to incubate without extreme sun exposure.

Although investigations of the causes of death of sun-exposed surf smelt spawn was beyond the scope of this study, it appears that upper intertidal beach-surface substrate temperatures on calm, clear days during the summer months in the Puget Sound basin can commonly reach in excess of 100 degrees F., possibly for extended periods during the daytime very low tides common in this region during that time of year (Penttila 1973). Surf smelt spawn deposits exposed on the beach surface to such harsh conditions appear to die within hours, presumably from the combined effects of thermal shock and desiccation. Given the rigorous marine environment that the surf smelt has evolved to utilize for spawning, its eggs are obviously adapted to withstand wide ranges of and abrupt fluctuations in salinity and temperature during incubation. The limits of their tolerance are routinely exceeded on sun-exposed beaches during the summer months. Given its wide geographical occurrence and year-round availability in a ripe condition, surf smelt should be quite amenable to *a priori* experimentation, in both the field and laboratory, to confirm the results of this study, and to investigate the effects of other environmental factors on this “generalized aquatic vertebrate” and its early life history stages.

During the colder fall-winter months, surf smelt spawn is able to survive well on sun-exposed beaches, as illustrated by monthly spawn mortality data collected from a sun-exposed spawning beach at March Point, Fidalgo Bay, that is frequented by spawning smelt on a year-round basis (Figure 3). At this site, summer spawn *in situ* mortalities commonly near 100%, while eggs deposited in the fall-winter experience mortalities in a much lower range, at or below that generally experienced by shaded summer spawn.

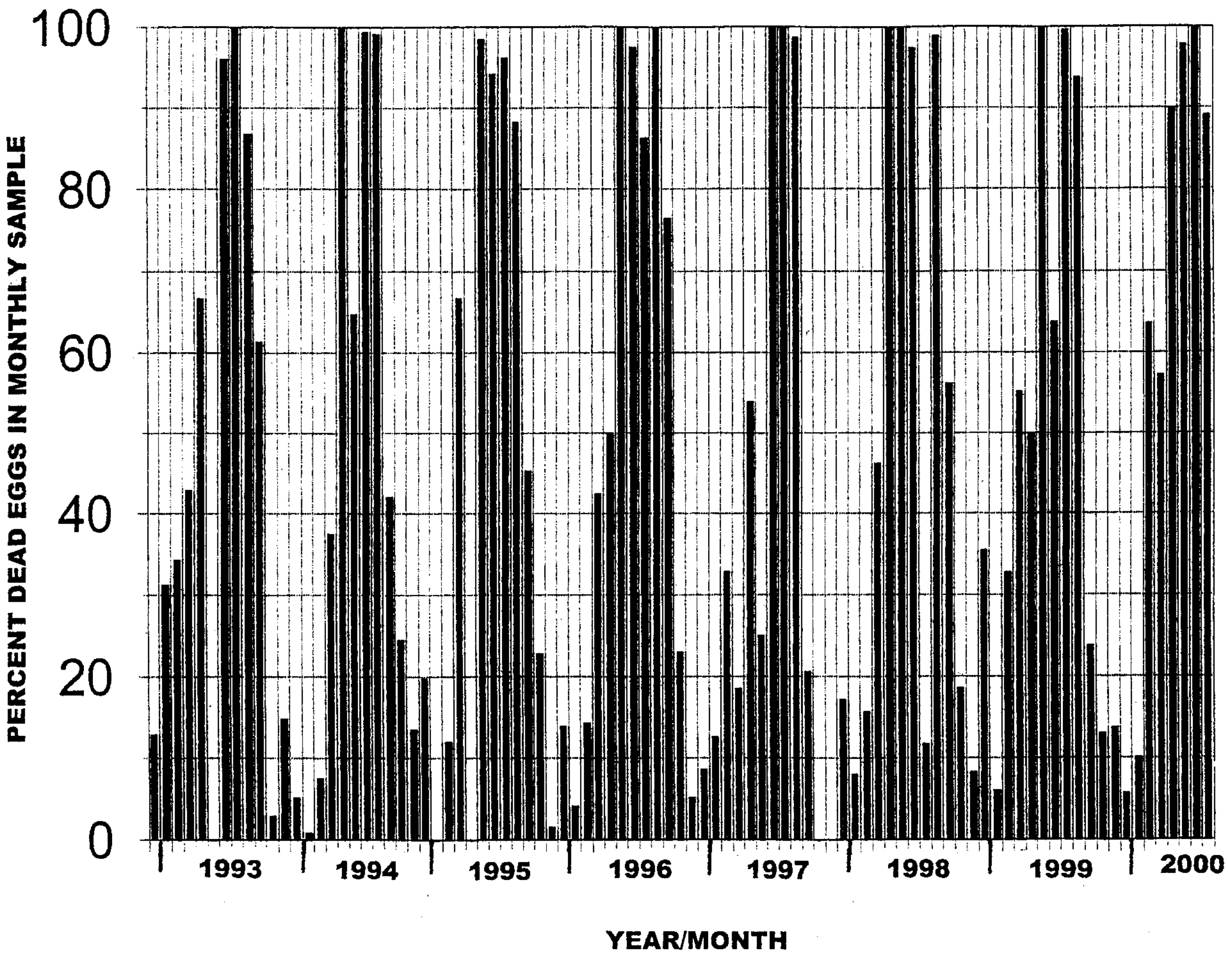

Figure 3. Monthly surf smelt spawn mortality data for an "unshaded" spawning beach at March Point, Fidalgo Island, Skagit County, WA. December 1992 through July 2000.

The primary local deciduous tree species that contribute to the shading canopies of a typical marine riparian corridor on a sheltered Puget Sound beach are the bigleaf maple (*Acer macrophyllum*), the red alder (*Alnus rubra*), and willows (*Salix ssp.*). These species appear to have a tolerance for exposure to sea-water, and it is not uncommon for their root-masses to be exposed at the seaward edge of the supralittoral zone, at or below the ordinary high water line. On a sheltered Puget Sound beach, overhanging tree canopies often span the entire width of the zone of potential surf smelt spawning substrate, which is commonly a band of mixed sand-gravel several meters wide, the upper edge of which is positioned at about the mean high water line (Figure 4). As the shorelines of Puget Sound evolve and change, so do the small-scale characteristics of the marine riparian vegetation corridor. The above tree species seem to be both ubiquitous and fast-growing, and respond relatively quickly to changes in the character of the supralittoral zone.

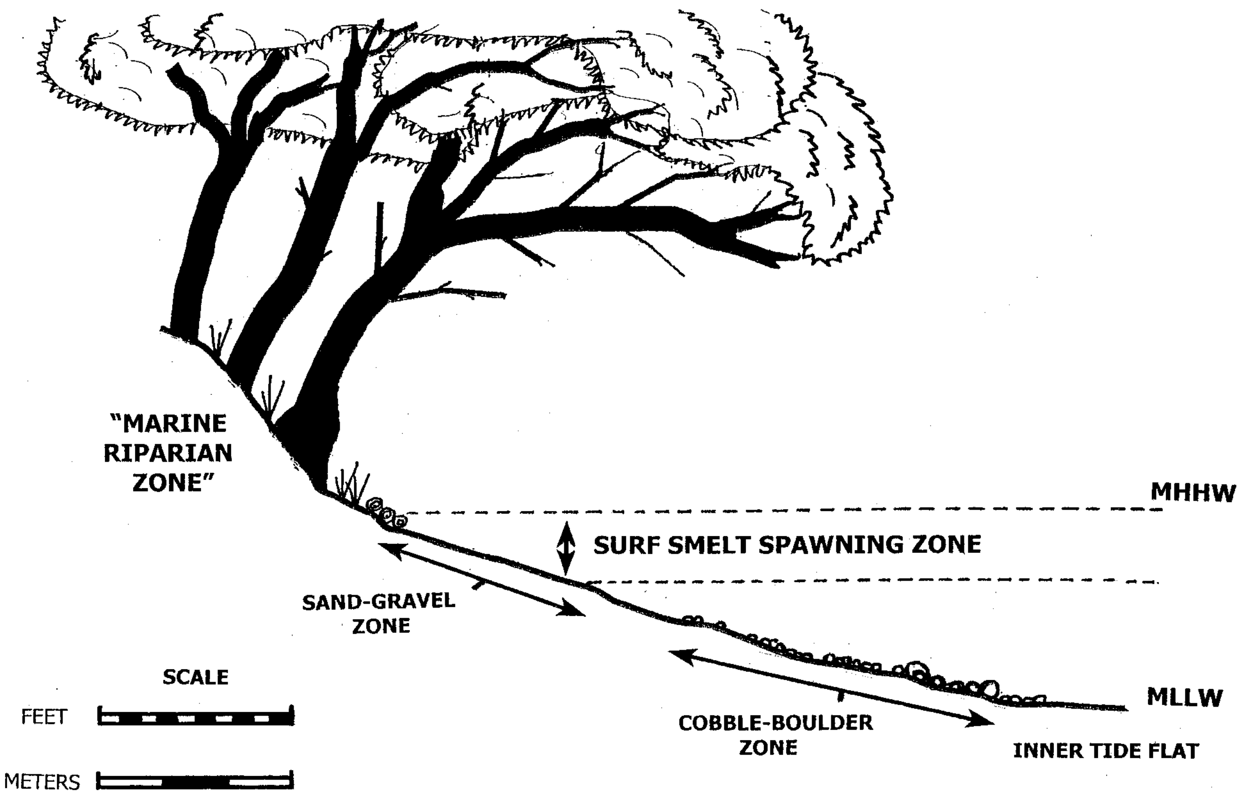

Figure 4. Generalized diagram of a "well-shaded" Puget Sound surf smelt spawning beach, with features approximately to scale.

The results of this study suggest that new attention should be given to the proper management, preservation and restoration of intact marine riparian forests and buffer zones along Puget Sound shorelines, habitats that are commonly heavily impacted by many human shoreline development activities. Active programs of reforestation of denuded shorelines would seem to be an option, to enhance and restore intertidal beach habitats for forage fish stocks, salmonids and other living natural resources.

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